JAEA's R & D Activities Related to Measurement and Detection of Nuclear Material and Nuclear Forensics for Nuclear Security and Safeguards

ISCN *Integrated Support Center for Nuclear Nonproliferation and Nuclear Security*

Japan Atomic Energy Agency JAEA

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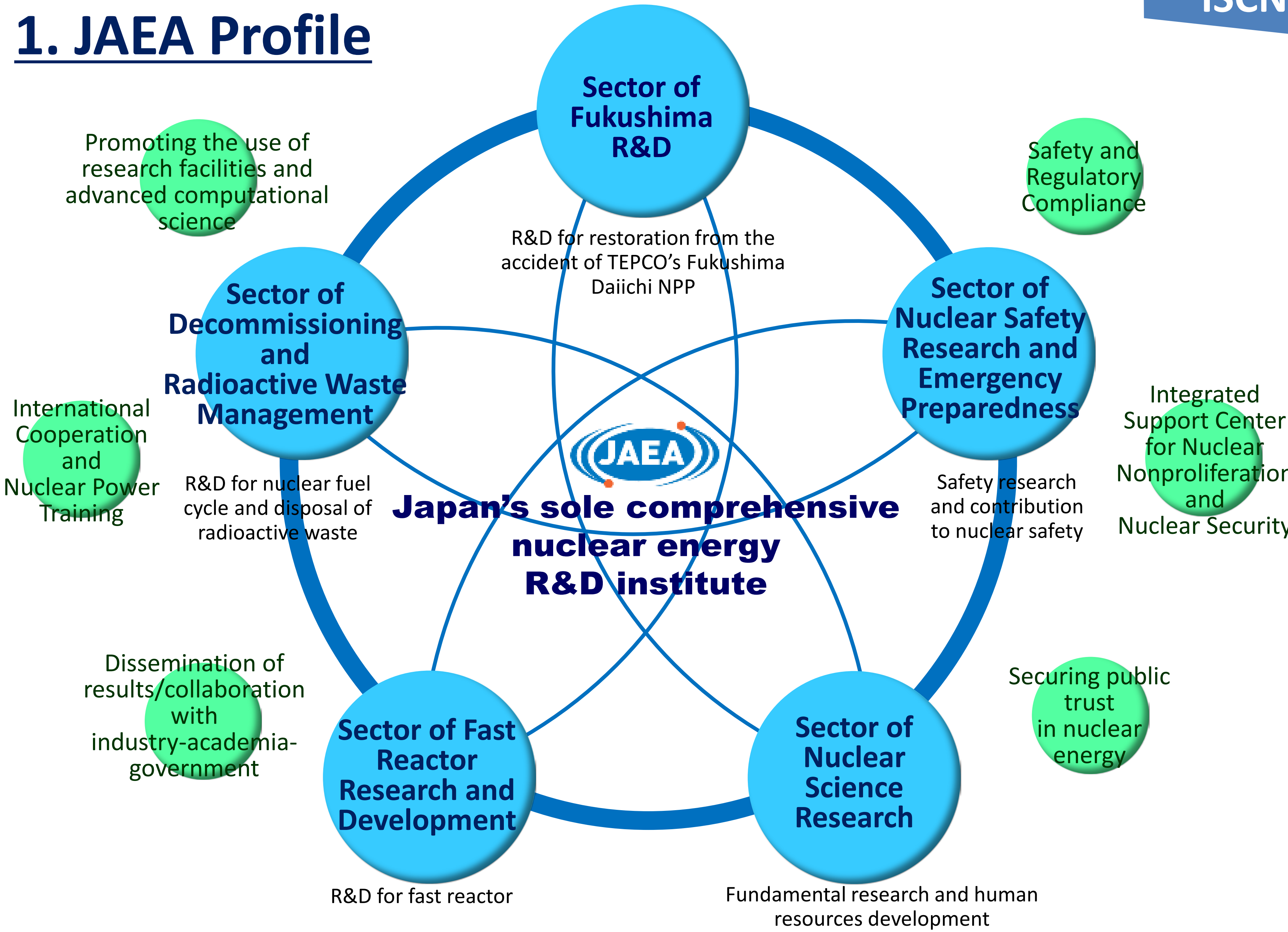
International Symposium on Technology Development for Nuclear Security

27 October 2016, Tokyo, Japan

1. JAEA Profile



2. Establishment of ISCN

Japan's National Statement at 2010 Nuclear Security Summit :

Establishment of an integrated support center for nuclear nonproliferation and nuclear security in JAEA and development of technology related to measurement and detection of nuclear material and nuclear forensics based on international cooperation

➡ **On December 27, 2010, ISCN was established in JAEA.**

Japan PM Speech at 2012 Nuclear Security Summit

"In particular, through our "ISCN" established in late 2010, Japan will expand its hosting and training of human resources. "

Japan PM Speech at 2014 Nuclear Security Summit

We will further promote research and development activities for leading-edge technologies including nuclear forensics and nuclear detection capabilities at JAEA.

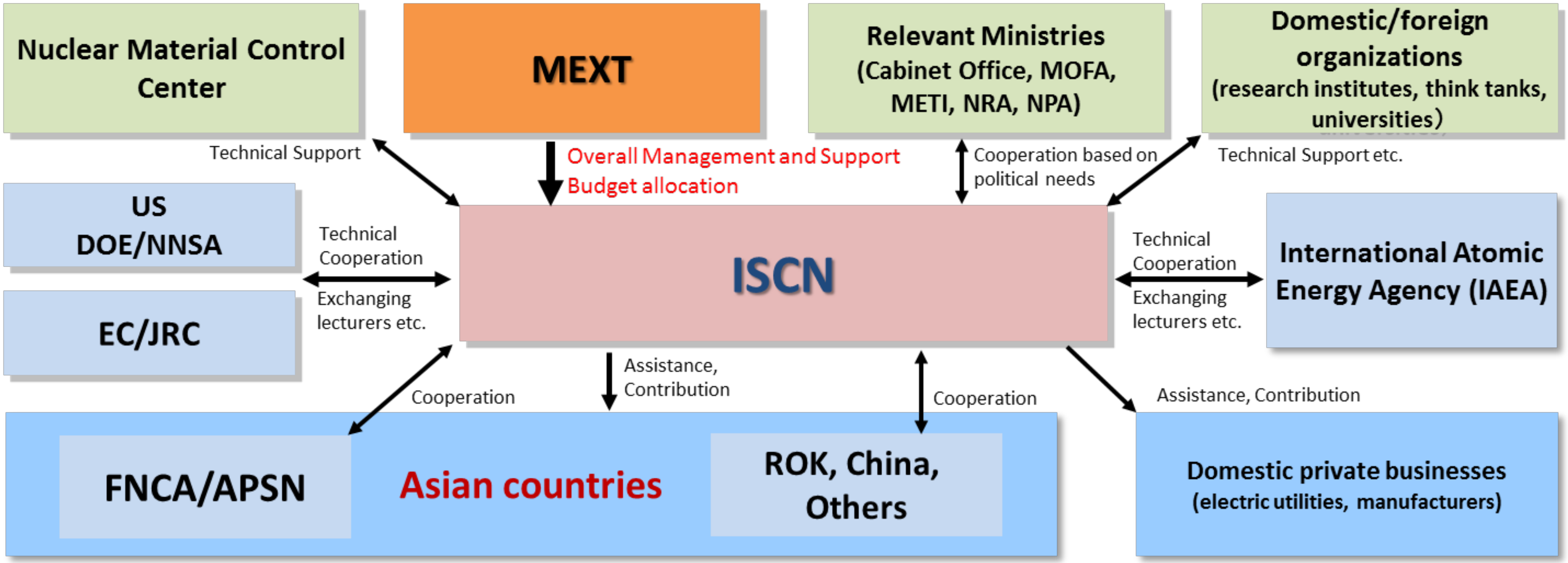
U.S.-Japan Joint Statement at 2016 Nuclear Security Summit

The United States especially applauds the indispensable role which the JAEA's ISCN is playing in the capacity building of personnel from other countries, particularly those from Asian countries, and expects ISCN to continue to serve as a leading Center of Excellence in this area.

3. ISCN's Main Activities and Cooperation with Domestic/Foreign Organizations

(1) R & D activities for nuclear nonproliferation (safeguards) and nuclear security
(2) Capacity building assistance through human resource development
(3) Support for CTBT
(4) Policy research on nuclear nonproliferation and nuclear security
(5) Support for nuclear material transport and management of research materials
(6) Public engagement (awareness raising, information sharing)

Structure of cooperation with domestic/foreign organizations

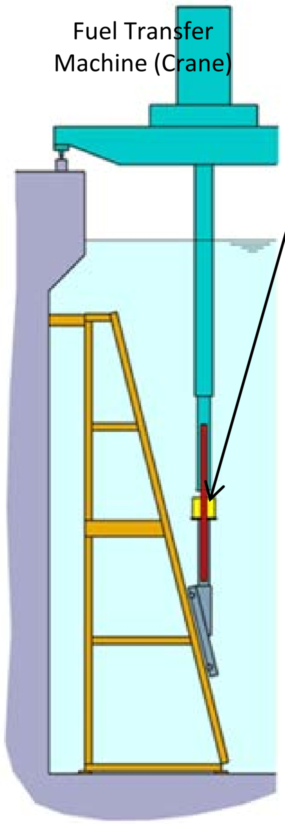


4. Technology Research and Development

4.1 Measurement and Detection of Nuclear Material (1/14)

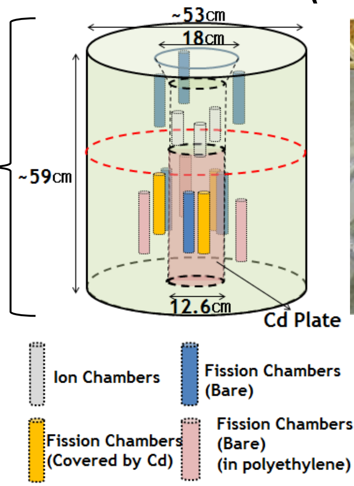
① Demonstration of a Spent Fuel Pu-NDA System (PNAR Detector) (JAEA-US joint)

Measurements of Fugen spent fuel assemblies were done under the collaboration of JAEA/DOE(LANL) in June 2013 (in the course of USDOE-NGSI spent fuel NDA program).



SFA Pool

PNAR Detector (developed by LANL)



Fugen Spent Fuel Assembly

PNAR Detector

PNAR detector developed by LANL was installed by JAEA in the Fugen spent fuel pool. Measurements / transfers of assemblies were done jointly.

PNAR: Passive Neutron Albedo Reactivity

; Quantifying ^{239}Pu-effective Mass

[^{239}Pu-effective= C_1*M(^{235}U) +M(^{239}Pu)+ C_2*M(^{241}Pu)]

Measured Fugen fuel Assemblies

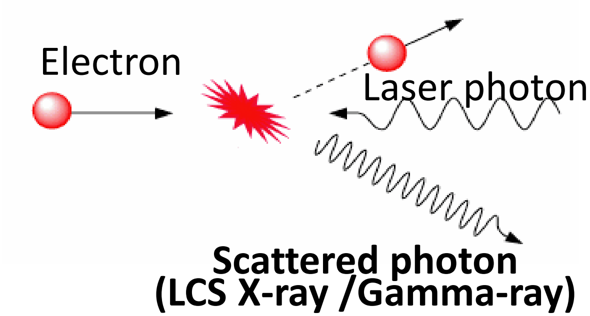
Type	Burn-up (GWd/MT)	Cooling Time (Years)
7 MOX type	3.7 – 19.2	10.2 – 19.8
1 UO_2 type	6.1	10.3

Measurements data is under evaluation for application of PNAR method to less Pu quantity assembly like Fugen's.

4.1 Measurement and Detection of Nuclear Material (2/14)

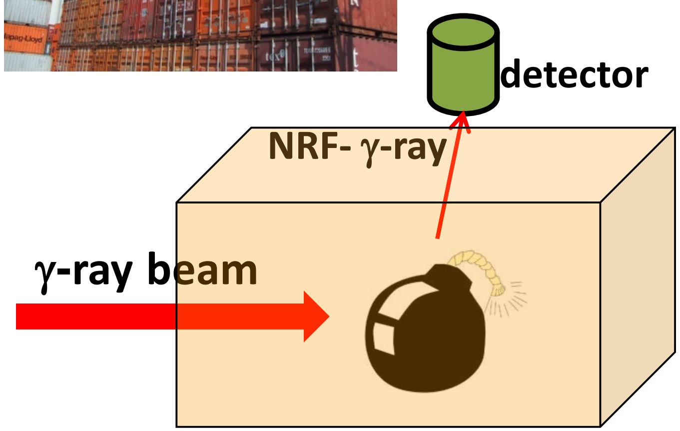
② Development of Nuclear Resonance Fluorescence NDA Technology

Laser Compton Scattering



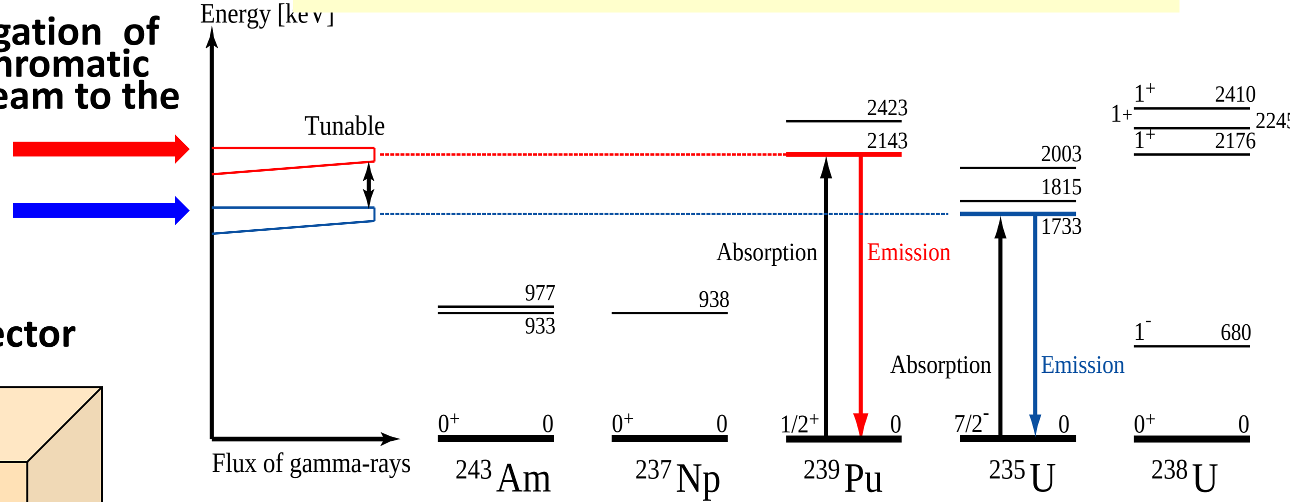
Generation of high intensity monochromatic X-ray /γ-ray beam (dE/E ~ 1%) using collimator

Interrogation of monochromatic γ-ray beam to the target



Nuclear material ?

NRF=Nuclear Resonance Fluorescence



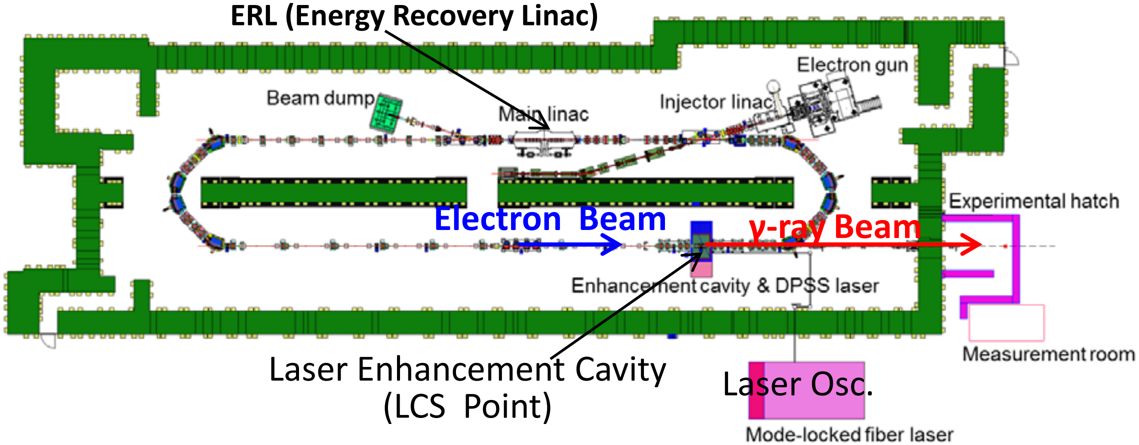
Nondestructive Detection using NRF

- ✓ Strong penetration of γ-ray
- ✓ Isotope specific detection
- ✓ No further radioactivation

4.1 Measurement and Detection of Nuclear Material (3/14)

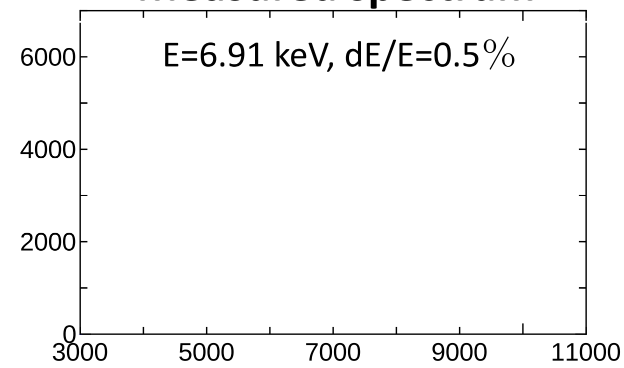
② Development of Nuclear Resonance Fluorescence NDA Technology

Demonstration of High Intensity Monochromatic X-/γ-rays Generation by LCS in March 2015 at Tsukuba (KEK)



LCS Demo-system based on ERL (@KEK)
Electron Beam = 20 MeV, 57 μA

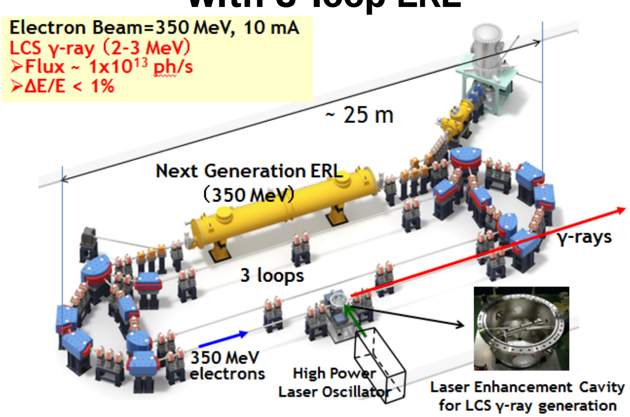
Measured spectrum



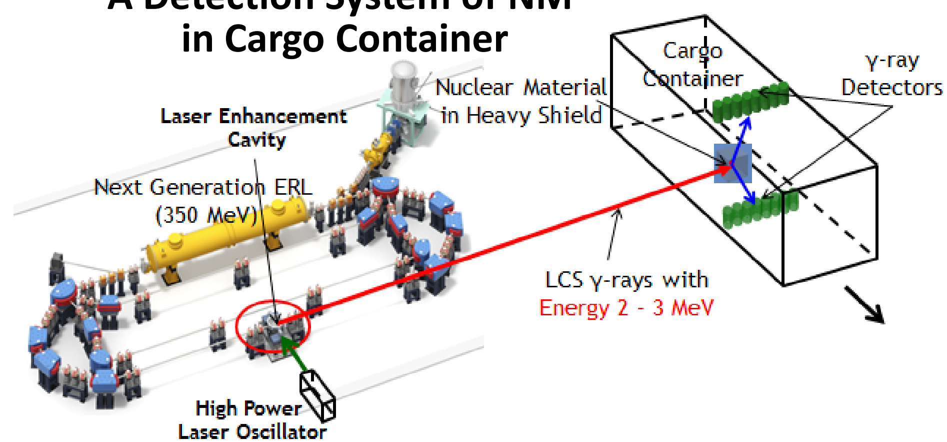
Intensity ; 9 x 10^8 ph/s/mA
[~100 times higher than the world highest]

Examples of Possible Applications of NRF NDA System using LCS γ-rays

A Future LCS Gamma-ray Source with 3-loop ERL



A Detection System of NM in Cargo Container



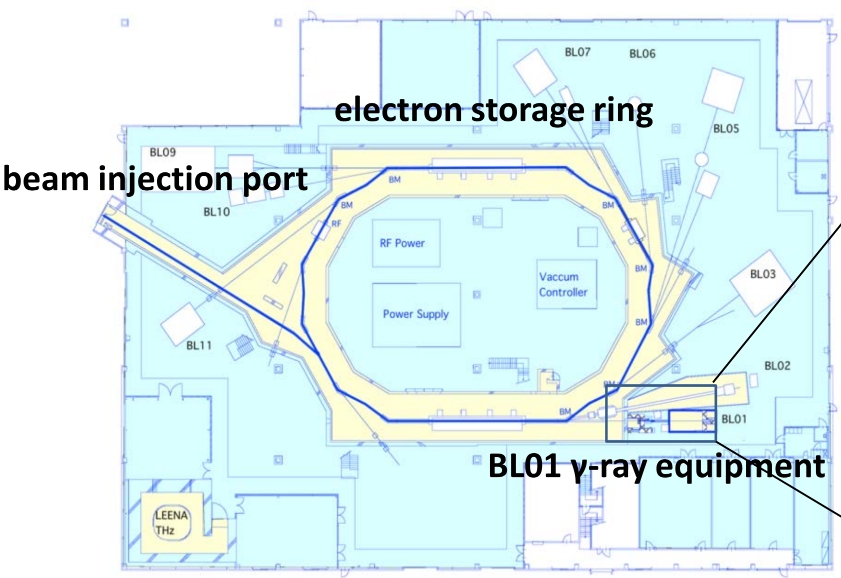
4.1 Measurement and Detection of Nuclear Material (12/14)

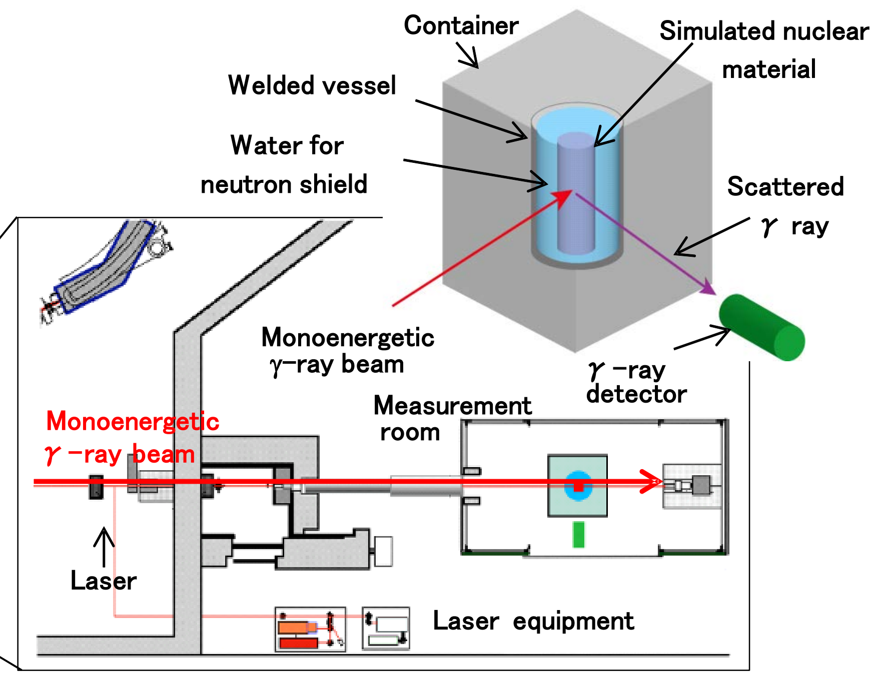
③ Demonstration of nuclear resonance fluorescence NDA technique

(2015JFY-2019JFY)

- **Demonstration of non-destructive detection of nuclear material (NM) in a heavily shielded container using NRF-NDA technique with actual energy (several MeV) γ-rays at New SUBARU of University of Hyogo**

New SUBARU synchrotron radiation facility





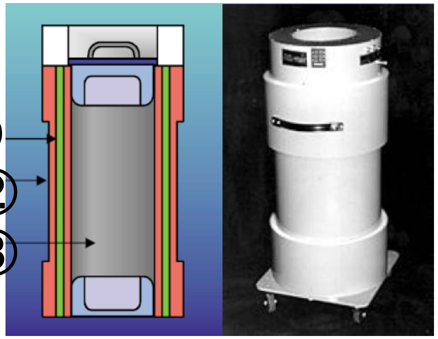
- **Improvement of NRFGeant4 code with taking coherent scattering effects into account for reproduction of the Bench-mark experiments at Duke University**

4.1 Measurement and Detection of Nuclear Material (4/14)

④ Development of He3-Alternative (Neutron) Detection Technology

In March 2011, IAEA requested member states to develop neutron detection technology using alternative to He-3 counters because of shortage of He-3 in near future.

NDA System for IAEA SG Verification HLNCC（An Example) (High Level Neutron Coincidence Counter)



①: He-3 proportional Counter
②: Polyethylene
③: Sample Cavity

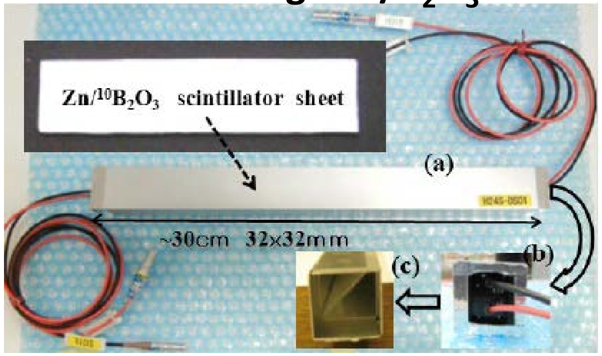
INVS; Inventory Sample Counter （A HLNCC type NCC）

IAEA requests to member states

- ✓ Almost the same size
- ✓ Almost the same weight
- ✓ The same price or cheaper
- ✓ Develop prototype in 3 years

JAEA Development of Alternative Neutron NDA Sys.

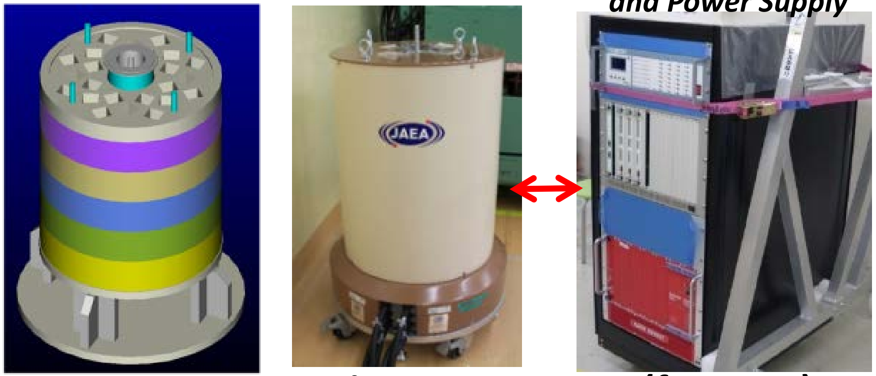
Neutron Detection Unit using ZnS/B_2O_3 Ceramic Scintillator



Alternate Sample Assay System (ASAS)

Neutron Counter

Data Processing Unit and Power Supply



A Demonstration NDA System (for INVS)
(24 ZnS/B_2O_3 Ceramic Scintillator Detection Units)

4.1 Measurement and Detection of Nuclear Material (5/14)

④ Development of He3-Alternative (Neutron) Detection Technology

Results of Comparative Demonstration of ASAS in March 2015

Demonstration of ASAS was done at PCDF-TRP(Tokai Reprocessing Plant) using actual MOX samples under an evaluation of specialists from IAEA, JRC and LANL .

	ASAS		INVS (IAEA)	
Counting Efficiency (e)	15.97%		30.82%	
Die-away Time (t in μs)	77.67		45.36	
Number of Tubes	24 ZnS/B_2O_3 Ceramic Scintillator Tubes		16 ^{3}He tubes	
Figure of Merit (FOM) <e^2/t>	**328.4**		**2094.1**	
Figure of Merit (FOM) <$e/t^{1/2}$>	**1.81**		**4.58**	
Total Measurement Uncertainty (Using MOX samples)	Passive Cal.	Known-α	Passive Cal.	Known-α
	3.91%	4.14%	3.66%	5.74%

ASAS
(Comparison with INVS)
- -Counting Efficiency is smaller
- -Die-away Time is longer
- -FOM is smaller

→ ASAS can be used in actual safeguards inspection.

4.1 Measurement and Detection of Nuclear Material (6/14)

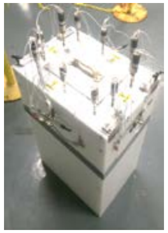
④ Development of He3-Alternative (Neutron) Detection Technology

(Development Period; March 2011 – May 2015)

Recently demonstrated HLNCC type NDA system using alternative counters to ^{3}He in the world

	Type of Counter (used in HLNCC type NDA Sys.)	Developer (Organization)	Demonstration	
			Time	Place
A	^{10}B lined counter (proportional counter)	US-ORNL/GERS	Oct. 2014	JRC-ITU (Ispra)
B	^{10}B (B_4C) Coated Straw Tube (proportional counter)	PTI (USA)	Oct. 2014	JRC-ITU (Ispra)
C	$ZnS/^{10}B_2O_3$ ceramic (scintillation counter)	JAEA	Mar. 2015	TRP-JAEA
D	parallel-plate boron-lined proportional counter	US-LANL/PDT	May 2015	TRP-JAEA
E	^{6}LiF/ZnS Blade (scintillation counter)	Symetrica	(Oct. 2014)	JRC-ITU (Ispra)
	Liquid scintillation counter	IAEA/JRC	Oct. 2014	JRC-ITU (Ispra)

A

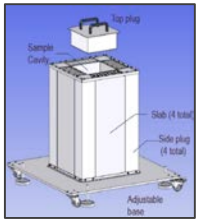


B

C

D

E



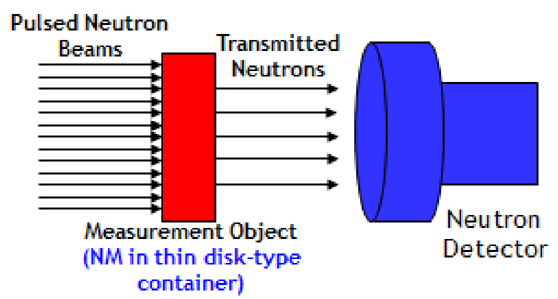
4.1 Measurement and Detection of Nuclear Material (7/14)

⑤ Development of Neutron Resonance Densitometry (JAEA-EC/JRC-IRMM Joint)

NRD: Neutron Resonance Densitometry

NRTA

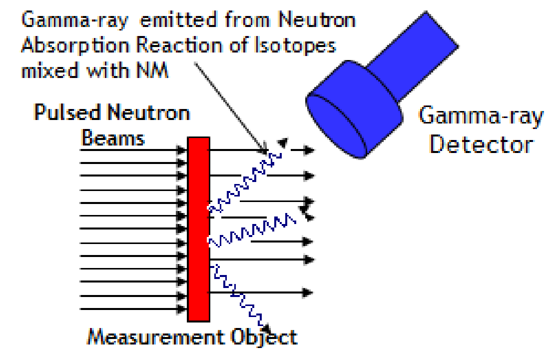
(NRTA: Neutron Resonance Transmission Analysis)



Quantification of (U/Pu) Isotopes
by Analyzing Transmitted Neutrons with Information of Resonance Absorptions by Isotopes

NRCA

(NRCA: Neutron Resonance Capture Analysis)



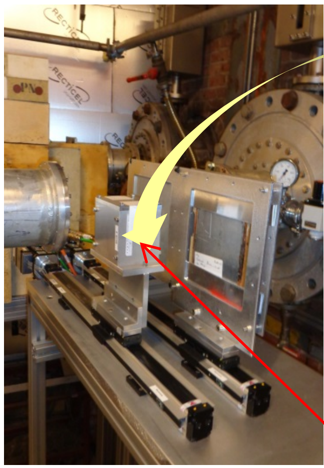
Quantification of Mixed-in Isotopes
by Analyzing Emitted Gamma-rays from Neutron Absorption Reactions
(Analysis of NRTA is corrected with the amount of neutron absorbers.)

NRD: A NDA method to quantify the amount of special nuclear materials (U/Pu) (each of U/Pu isotopes) in samples with unknown elemental and isotopic composition, (such as melted fuel debris generated in severe accidents of nuclear reactors)
NRD : A non-destructive mass spectrometry method

4.1 Measurement and Detection of Nuclear Material (8/14)

⑤ Development of Neutron Resonance Densitometry (JAEA-EC/JRC-IRMM Joint)

Demonstration Experiments at GELINA in March 2015



Unknown samples (plates) were placed in the box.
Then measurement were performed.

Au, W, Rh, Cu, Co, Mn samples (plates) with different thicknesses were prepared .

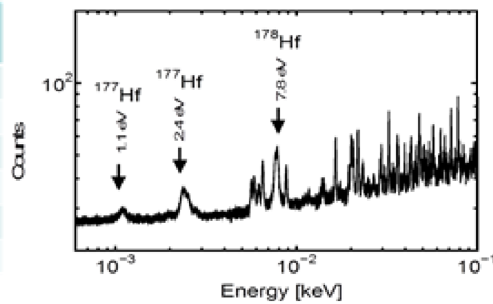
For NRTA unknown number of samples were placed in the box then sealed.

	atoms/barn				
	declared	determined	uncertainty	C/E	uncertainty
Au	0.000E+00			0.0000	0.0000
W	2.269E-03	2.250E-03	2.2E-06	0.9916	0.0010
Rh	1.856E-03	1.891E-03	3.1E-06	1.0190	0.0017
Nb	5.485E-03	5.382E-03	1.0E-05	0.9812	0.0019
Cu	0.000E+00			0.0000	0.0000
Co	4.583E-03	4.509E-03	1.3E-05	0.9838	0.0029
Mn	1.901E-02	1.928E-02	2.8E-05	1.0140	0.0015

→By NRTA unknown samples were identified and quantities of elements were determined with difference less than 2%.

For NRCA/PGA unknown number of samples were placed in the box then sealed.

Element	*In Black Box? (Yes/No)*	Confirmation
Fe	*No*	
Ni	*Yes*	X
Cr	*No*	
B	*No*	
Gd	*Yes*	X
Hf	*Yes*	X



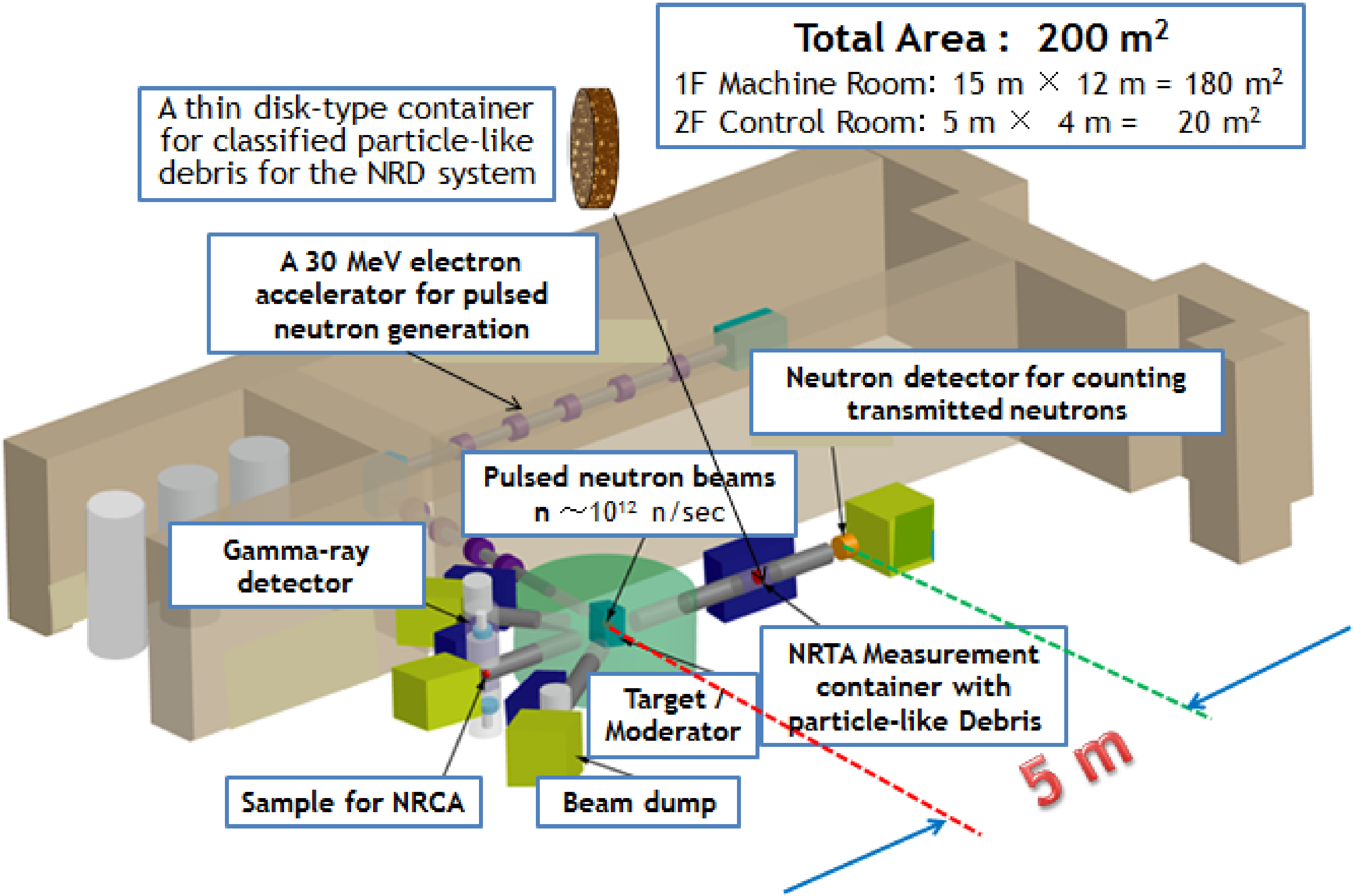
→By NRCA/PGA unknown samples were identified.

4.1 Measurement and Detection of Nuclear Material (9/14)

⑤ Development of Neutron Resonance Densitometry (JAEA-EC/JRC-IRMM Joint)

A Picture of a Practical NRD System

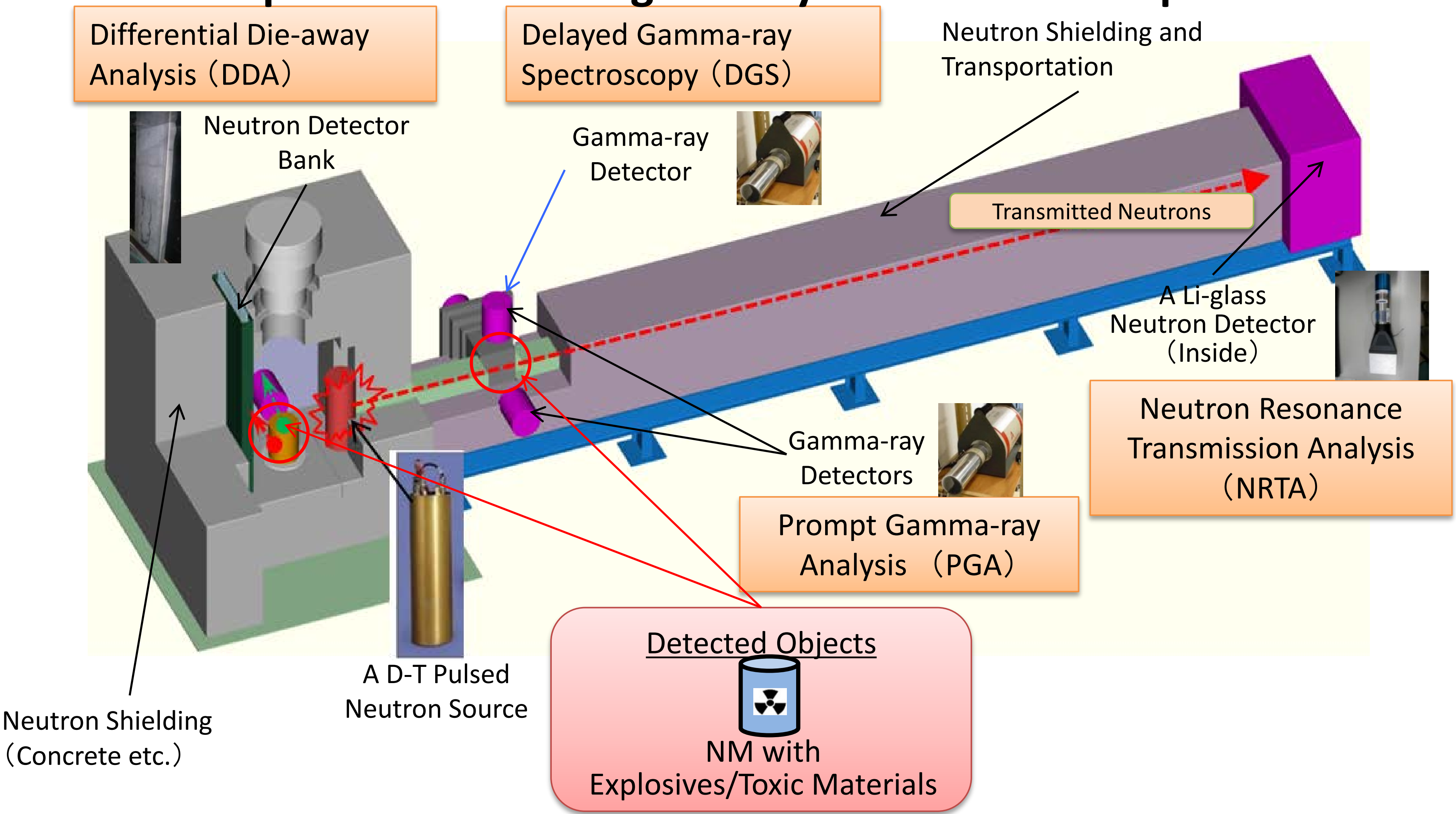
Accuracy of NRD: ~3 % ⇒ Accuracy level of partial defect test



4.1 Measurement and Detection of Nuclear Material (10/14)

⑥ Development of Active Neutron NDA Techniques (JAEA-EC/JRC Joint)
(2015JFY-2017JFY)

A picture of the integrated system of 4 techniques



4.1 Measurement and Detection of Nuclear Material (11/14)

⑥ Development of Active Neutron NDA Techniques (JAEA-EC/JRC Joint)

Active (D-T Source) neutron NDA techniques to be developed

Active NDA Techniques	What Quantified / Identified
DDA: Differential Die-away Analysis	^{239}Pu-effective
DGS: Delayed Gamma-ray Spectroscopy	Ratio of ^{235}U/^{239}Pu/^{241}Pu
NRTA: Neutron Resonance Transmission Analysis	Quantity of each of U/Pu isotopes
PGA/ NRCA Prompt Gamma-ray Analysis Neutron Resonance Transmission Analysis	Existence of explosives / toxic materials

4.1 Measurement and Detection of Nuclear Material (13/14)

⑦ Advanced plutonium direct monitoring technical development(Japan-US joint)

Overview

- In reprocessing plant, Pu including FP is stored and has very high radioactivity.
- Establishing real-time measurement and continuous monitoring technology is necessary for enhancement and effectiveness of safeguards.
- A challenge (feasibility study) of development of a new technology has been started to measure and monitor Pu with FP in the storage under the joint research program between US/DOE and MEXT.

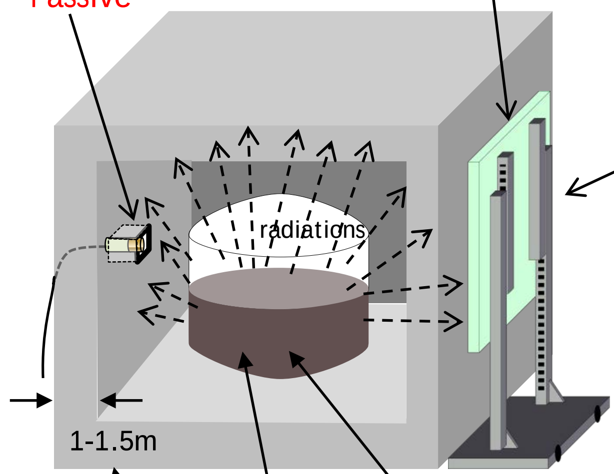
Expected Effects and Results

- This technology can be applied to real time monitoring for entire reprocessing process.
- It can be used for verification of waste material generated from dismantling operation.
- Continuous monitoring technology can be extended to detect security events.

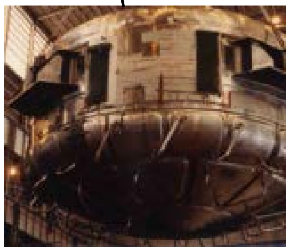
Implementation

2015-2017 (3years)

Image of Pu monitoring technology development



Example of a detector



High Active Liquid Waste tank

Design and Composition Survey
- Pu concentration
- density
- Pu isotopic composition
- impurity contents and nuclides etc.

↓

Radiation Study
Various radiation measurements

↓

Simulation
evaluation of candidate technologies

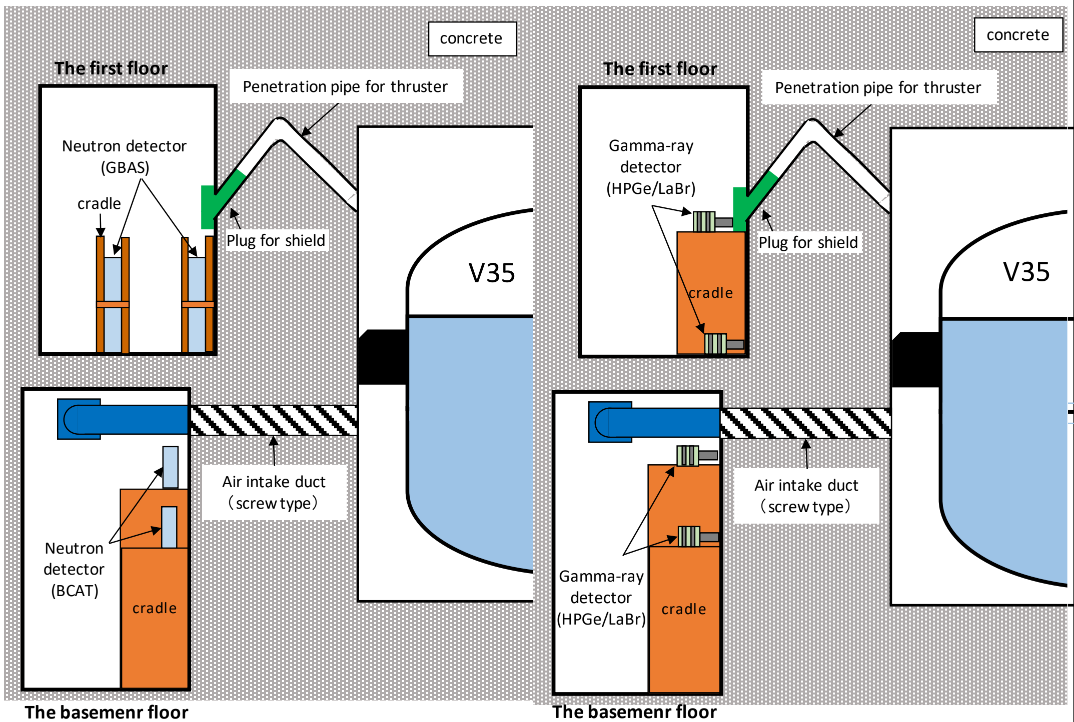
※High Energy Gamma and Elementary particle are planned to be measured.

4.1 Measurement and Detection of Nuclear Material (14/14)

⑦ Advanced plutonium direct monitoring technical development(Japan-US joint)

Achievement of FY2015

- Collection of design information of High Active Solid Liquid Waste (HAW) tank for MCNP modeling.
- Destructive analysis on HAW samples and investigation of representative and available nuclides and the intensities for MCNP modeling.
- Preliminary measurements of the radiation characteristics (γ and n) emitted from HAW tank at the outside of the concrete cell.



Plan of FY2016

- MCNP simulation for the detector optimization.
- Preliminary measurements of the radiation characteristics in concrete cell.
- Conceptual design of customized detector will be carried out.

Overview of the preliminary radiation measurement

4 Technology Research and Development

4.2 Development of Nuclear Forensics Capabilities(1/3)

Japan's National Statement at Nuclear Security Summit (Washington D.D. April 2010)

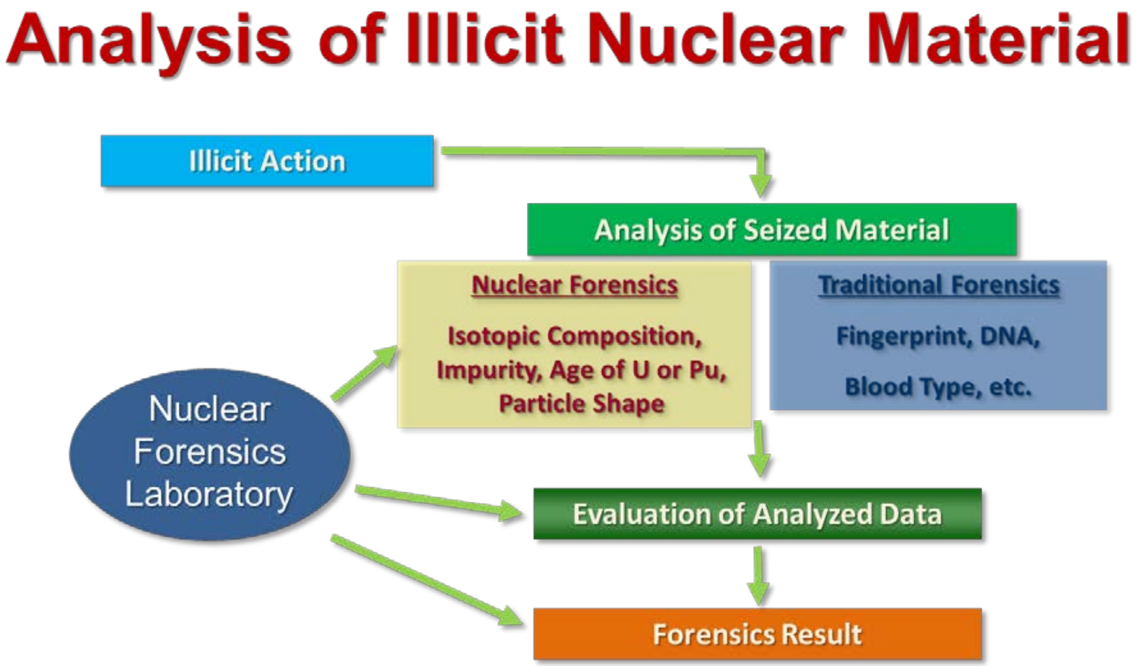
Development of analysis, detection, and capability of nuclear forensics
Japan will establish more precise and accurate capabilities in detection and forensic within a three year time frame, and sharing the fruits of these new technologies with the international community

Nuclear Forensics (NF) ?

Process of identifying the source of nuclear or radioactive material used in illegal activities, to determine the point of origin and routes of transit involving such materials.

"Attributions" of nuclear and radioactive materials

- What is this ?
- What's the purpose ?
- When is it produced ?
- Where is it produced ?
- How is it produced ?



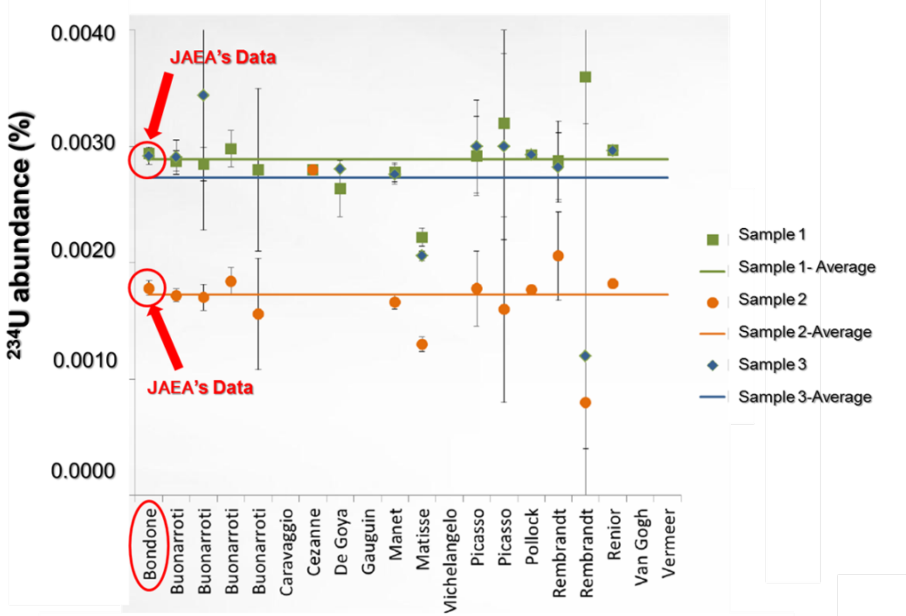
4.2 Development of Nuclear Forensics Capabilities(2/3)

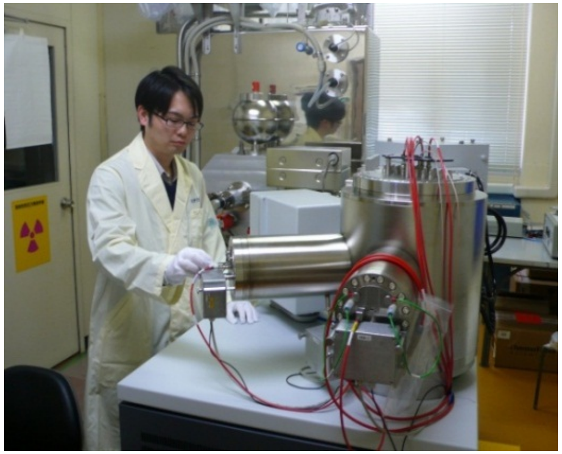
Technical Research and Development in JAEA

- Establishment of NF Analysis Lab (analytical devices and system)
- Impurity measurement
- Particle analysis
- Uranium age determination
- Development of prototype National NF Library (NNFL)

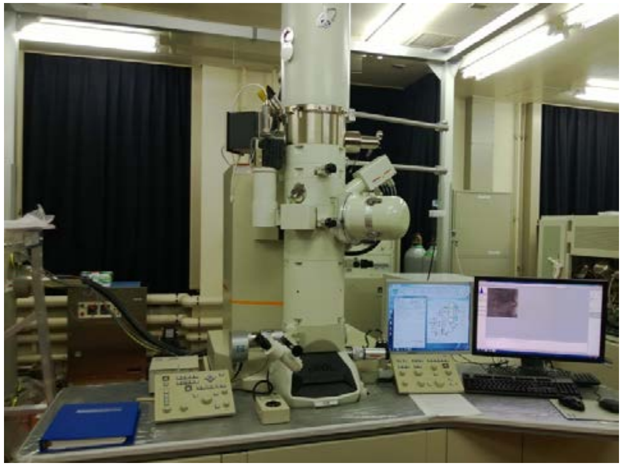
Isotopic Composition Measurement

A result of Nuclear Forensics International Technical Working Group (ITWG) Collaborative Materials Exercise 4 (CMX-4)





Thermal Ionization Mass Spectrometry



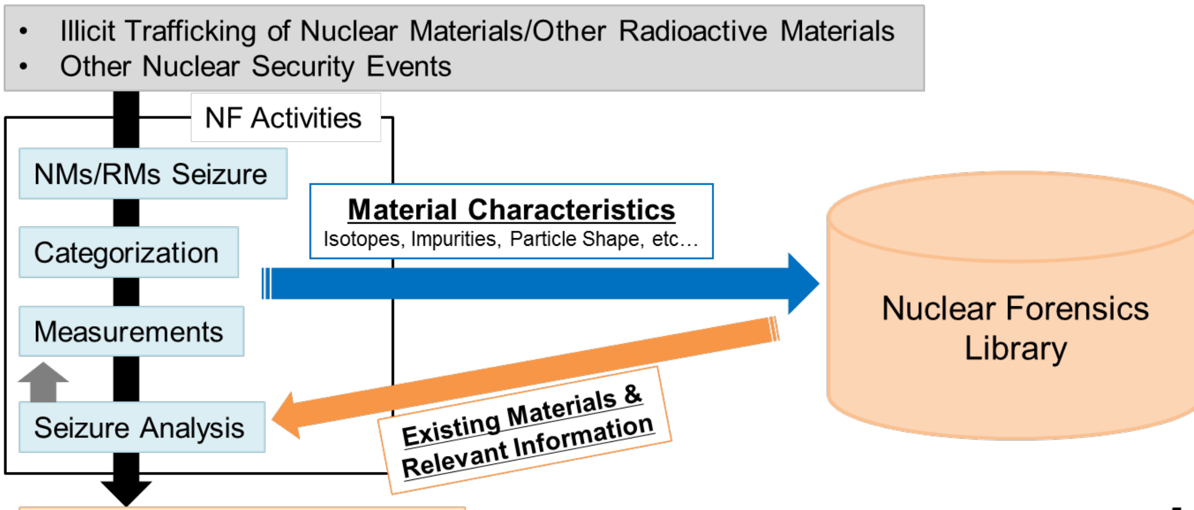
Transmission Electron Microscope

4.2 Development of Nuclear Forensics Capabilities(3/3)

Basic Idea of NNFL

Nuclear Forensics Library*

Organized collection of data and information about nuclear and other radioactive materials produced, used, or stored in the past.



*J.F. WACKER, et. al. "Proposed Framework for National Nuclear Forensics Libraries and International Directions," PNNL-SA-70589 (2011).

5

We encourage further international cooperation within the IAEA and other relevant international organizations, aimed at
(1) connecting and enhancing traditional and nuclear forensics capabilities
(2) establishing national nuclear forensics databases
(3rd The Hague Nuclear Security Summit Communiqué)

5. Summary

- **In order to contribute for strengthening international nuclear nonproliferation and nuclear security, ISCN/JAEA conducted R & D on nuclear material measurement and detection technologies making the best use of its capacity as a comprehensive nuclear energy institute in collaboration with international partners.**
- **ISCN/JAEA obtained various outcomes through those activities, which were further disseminated to IAEA and international community.**

Thank you for your attention.

Please visit our website! **http://www.jaea.go.jp/04/iscn/index_en.html**

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